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Making Sense of Smartness in the Context of Smart Devices and Smart Systems

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Abstract
Careless usage of the term *smart* in today's world leads to wondering whether it means anything beyond involving a currently impressive application of IT. This paper characterizes smart and smartness in relation to describing, analyzing, and designing smart devices and systems. Examples of nominally smart devices and systems and principles that support thinking about smartness lead to a definition of smartness in the context of devices and systems. The definition leads to a classification matrix for smart capabilities organized around four categories: information processing, internal regulation, action in the world, and knowledge acquisition. Each category includes a set of separate capabilities that can be described on a continuum from not smart to somewhat smart to extremely smart based on the definition of smart. A concluding section describes how this multidimensional view of smartness can be applied in thinking about smartness while describing, analyzing, and designing devices and systems.

Keywords Smart device · Smart system · Smart service system

1 Trying to Define Smart in the Context of Smart Devices and Systems

This research essay proposes a set of usable ideas related to the smartness of systems and devices. That topic is important because the term smart is used increasingly to describe "smart" things (e.g., smart devices, smart systems, smart cities) but often is not defined clearly in that context. Instead, smart often brings vague connotations related to using computerized information and somehow mimicking properties related to the original meaning of smart as a description of a person's intelligence and practical ability. This essay goes beyond defining smartness in a way that fits devices and systems. It looks at smartness of devices and systems in substantial detail by expanding a proposed definition into a series of separate capabilities that are organized under four categories. Identification of those capabilities leads to a set of design dimensions that can be used to characterize devices and systems. The ultimate goal of identifying those design dimensions is to make the term smart as useful as possible for describing, analyzing, and designing devices and systems.

Background Imagery related to machine intelligence has existed for many decades. A widely repeated story involves the way a Univac 1 computer contradicted pundits by projecting that Dwight Eisenhower would win the United States presidential election of 1952. (Goff 1999; History of Computing Project 2018). At the time such machines sometimes were referred to as wondrous "electronic brains" (Chinoy 2010, p. 22). Four years later, the 1956 Dartmouth Summer Research Project on Artificial Intelligence marked the beginning of serious research related to artificial intelligence. Ever since then, the idea of what is or is not artificial intelligence has been a moving target, with previously hard-to-imagine capabilities such as usable speech recognition becoming mundane. The many streams of subsequent research and practice related to artificial intelligence, computer science, statistics, and other fields have brought concepts, methods, experience, and a great deal of techno-hype and salesmanship related to subjects such as machine learning, big data, Internet of Things, and recently, cognitive computing (e.g., IBM 2018).

Today, long after an "electronic brain" projected the winner of the 1952 election, things are often deemed "smart" without

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a clear notion of what smart means. For example, three recent calls for papers (CFPs) in the IS discipline emphasized various types of smart things but seemed unable, unwilling, or uninterested in defining that term.

- The CFP of the IFIP 8.6 workshop on “Smart Living, Working, and Organizing” prior to ECIS 2018 did not define smart, but mentioned smart devices, smart homes, smart cars, smart phones, smart government, smart cities, and smart organizations.
- The CFP for the HICSS Minitrack on “Smart Service Systems” in January 2019 implied that smart service systems involve smart services or smart devices, but did not define those terms. Later that CFP noted a preference for smart service systems that use analytics or cognitive computing, topics that may or may not be related to the “smart living, working, and organizing” theme of the IFIP workshop.
- A 2018 CFP for a special issues of the *Journal of the Association for Information Systems (JAIS)* starts by citing a *2018 Tech Trends Report (*Future Today Institute 2018) in which ‘smart’ appears 269 times but did not define the term and did not mention that examples in the report include smart contracts, smart dust, smart fabrics, smart kitchens, smart mirrors, and smart shoes. Across several paragraphs the CFP associated “smart” with terms that might come from a consulting company’s marketing brochure: artificial intelligence, unprecedented smart services, intelligent data analyses, creative IT systems, cross disciplinary, disruptive, emerging value networks, and innovative technologies (including soft robots, image and voice recognition, blockchain mechanisms, and unmanned vehicles).

The difficulty of producing a general and usable definition of smartness in the context of systems and devices is apparent from the diversity of topics in the above CFPs and from the wide range of other things that are described or even identified as smart. For example, things not mentioned in the above CFPs but identified as smart in Wikipedia articles include, among many others: smart bombs, smart cameras, smart doorbells, smart file systems, smart glass, smart grids, smart highways, smart locks, smart manufacturing, smart meters, smart pensions, smart power, and smart whiteboards. In the world of technology products, Microsoft Word 2016 touts nominally smart capabilities including smart quotes, smart lookup, smart copy and paste, smart paragraph selection, and smart cursoring. One might wonder whether those capabilities really deserve the name smart. Similar issues appear in related areas. For example, Sugumaran et al. (2017) notes that computational intelligence has acquired many definitions during the 20 years since that term was coined.

Does Smart Mean Anything in Particular? It is difficult to say something nontrivial about smartness that applies across the diversity of examples above. That diversity leads to doubting whether saying that those things are smart implies that they actually have common properties beyond using IT in a way that seems impressive. Serious discussion of smart X needs to define what smart means in relation to IT-enabled devices and systems. (Note again that this discussion is unrelated to traditional uses of smart involving smart people or clever design.)

Viewed more broadly, one might wonder whether it would be fruitful, or even possible to theorize or generalize about the nature or impacts of smartness if the same concept purports to describe so many things that are fundamentally different in form, function, size, and significance. For example, a definition of smart that emphasizes the application of the Internet of Things (IoT), artificial intelligence, big data, or cognitive computing would automatically disqualify many supposedly smart systems or devices that do not use those approaches.

Goal and Organization This research essay provides a conceptual basis for making sense of smartness in the context of smart devices and smart systems. Making sense of smartness in that context is necessary if discussions of that topic are to move beyond unrelated examples, scattered predictions, social criticism, and/or philosophizing based on whatever seems interesting or potentially profitable to whomever is writing or speaking.

Goal: Characterize smart and smartness in relation to devices and systems in a way that is useful for describing, analyzing, and designing devices and systems.

The next section identifies principles that can be applied in thinking about the concept of smartness as it might apply to the various examples mentioned above. The principles are capability-orientation, context-dependence, multidimensionality, separability, and applicability to devices, automated systems, and sociotechnical systems. The principles lead to a definition of smartness in the context of devices and systems. The definition leads to a classification matrix for smart capabilities, which are subdivided into four categories, information processing, internal regulation, action in the world, and knowledge acquisition. Each of those categories includes a set of separate capabilities that each can be described on a dimension from not smart to somewhat smart to extremely smart based on the definition of smart. A concluding section describes how this multidimensional view of smartness can be applied in thinking about smartness while describing, analyzing, and designing devices and systems. Except for a brief comment near the end, this paper focuses almost entirely on understanding what smart might mean in the context of devices and systems. It does not cover important topics concerning conflicting stakeholder interests such as privacy, autonomy, job satisfaction, equity, and wealth.

2 Principles Related to Defining Smart and Smartness

This paper's view of smart and smartness is related to purposefully constructed entities including devices, sociotechnical systems, and totally automated systems. It explicitly excludes consideration of smart or smartness as a characteristic of people, of groups of people, or of natural capabilities of living things, such as an ant colony's ability to coordinate activities of colony members that perform different roles. It assumes that methods and research associated with artificial intelligence may or may not apply to the devices and systems mentioned above.

This paper's consideration of smartness is guided by a set of principles that are introduced here to make it easier to understand how this paper's ideas unfold. These principles were not found in the existing literature. Instead, they coalesced as the paper's ideas were being developed while searching for sources of insights related to the concepts of smart and smartness. Thus, while other researchers might have settled on other principles or no principles at all, the following principles are useful for understanding the ideas that will be presented in the rest of this paper.

Capability-Orientation An entity's smartness is described in terms of its capabilities for performing types of actions that are associated with smartness. Thus, a device or system's smartness along the various dimensions of smartness can be assessed by observing how it operates. This principle of capability-orientation implies that non-functional physical features or aspects of appearance are not relevant to whether a device or system is smart.

Context-Dependence An entity that might seem smart along some of the dimensions of smartness within a context might be totally unsmart on those dimensions in another context. For example, a device or system that seems smart in the context of dealing with minor variations in a highly repetitive situation might be unable to function in the presence of high variation.

Multidimensionality Smartness is not a binary, yes/no distinction. Smartness can be viewed as a set of continuous variables or dimensions that individually range from not at all smart to extremely smart. The dimensions are assumed to be only partially independent, i.e. that smartness on one dimension often is partially dependent on smartness along another dimension. While it is always possible to combine any set of numerical dimensions into a single numerical score (e.g., the average of numerical scores for 10 dimensions), there is little reason to believe that a combined smartness score is genuinely useful for describing or comparing entities with regard to smartness.

The idea of visualizing smartness or intelligence as comprising multiple dimensions is not new. Gardner's (2008) updated book on multiple intelligence theory has been cited over 13,000 times. It notes that the original intelligences from research two decades earlier include: musical intelligence, bodily-kinesthetic intelligence, logical-mathematical intelligence, linguistic intelligence, spatial intelligence, interpersonal intelligence, and intrapersonal intelligence. Those intelligences are portrayed as existing separately but sometimes working together. Goleman's (1995) book on emotional intelligence, which has been cited over 35,000 times, also separates one type of intelligence from another. A final example of multidimensionality is the Myers-Briggs Type Indicator (e.g., Myers-Briggs Foundation 2019), which defines four dimensions for describing personal psychological preferences in everyday life (extraversion vs. introversion, sensing vs. intuition, thinking vs. feeling, and judging vs. perceiving). It is not about intelligence, but is another widely used set of dimensions, in this instance for helping people understand themselves and how their psychological preferences affect their perceptions, decisions, and behavior in the world.

Separability An entity that includes or uses a nominally smart component may not be smart of its own right. For example, a hospital that uses smart thermometers may not be smart in terms of most or all of the dimensions of smartness. Similarly, having an exceptionally smart exhaust system does not imply that an entire car should be viewed as smart.

Applicability to Devices, Totally Automated Systems, and Sociotechnical Systems Totally automated systems are increasingly evident as subsystems of sociotechnical systems. The dimensions of smartness should make sense for devices, for totally automated systems, and for sociotechnical systems.

3 Definition of Smart

This section defines smart and related dimensions of smartness in a way that applies to devices, totally automated systems, and sociotechnical systems with human participants. Relevance to all three areas is essential. The powerful trend toward automating important parts of business operations will lead to many situations in which it may not be obvious whether a smartness initiative should be directed at an entire sociotechnical system or at specific components.

3.1 Proposed Definition of Smart

The introduction noted the difficulty of trying to define smart in a nontrivial way that applies to most of nominally smart things that it mentions. Searches of Google Scholar for various "smart" things (e.g., smart phones, smart cities, etc.) or intelligent things (e.g., intelligent machines, intelligent databases, etc.) did not come close to producing a consensus definition that is useful here. Subsequent searches of the eLibrary of the Association for Information Systems only provided a few hints, as is explained in the Appendix.

Ultimately, ideas about smart service systems from Medina-Borja (2015), an editorial in the journal *Service Science,* provided the most useful hint at a possible direction for thinking about a notion of smartness that covers the Internet of Things, artificial intelligence, and the smart things mentioned in the introduction. That view of smart service systems is based partly on a 2014 call for research proposals from the US National Science Foundation. The editorial defines smart service system as:

> "a system capable of learning, dynamic adaptation, and decision making based upon data received, transmitted, and/or processed to improve its response to a future situation. The system does so through self-detection, self-diagnosing, self-correcting, self-monitoring, self-organizing, self-replicating, or self-controlled functions. These capabilities are the result of the incorporation of technologies for sensing, actuation, coordination, communication, control, etc."

Most of the nominally smart things mentioned in this paper's introduction exhibit aspects of some of those capabilities. A view of smartness that combines those ideas with the general spirit of the five principles mentioned earlier calls for at least some automated information processing and at least some degree of self-control, learning, adaptation, and/or decision-making related to performing activities or functions that have consequence in the world. That leads to the following definition of smartness in the context of devices and systems:

> **Definition of smartness**. Purposefully designed entity X is smart to the extent to which it performs and controls functions that attempt to produce useful results through activities that apply automated capabilities and other physical, informational, technical, and intellectual resources for processing information, interpreting information, and/or learning from information that may or may not be specified by its designers.

Specific aspects of the definition should be noted:

"Purposefully designed entity." The entities under consideration are designed. They are artificial (Simon 1996) and do not occur in nature. They may have evolved through many iterations that involve at least some degree of conscious design effort, either through formal projects with allocated resources or through workarounds and adaptations to overcome limitations of previously existing versions of device or system.

"Smart to the extent to which." Smartness is not a binary, yes/no variable that describes whether something is or is not smart. Instead, as defined here, smartness is a combination of continuous variables related to different aspects of smartness.

"Performs and controls functions that attempt to produce useful results." This phrase is stated in a way that applies to devices, sociotechnical systems, and totally automated systems. Specifying that the functions attempt produce useful results implies that those results may or may not be attained. Those functions may be performed in a way that is readily perceptible by the beneficiaries but also may be performed as automated activities deep within computing infrastructures that only technicians recognize. Smart functions may or may not be among the most important aspect of a situation. For example, consistent with the principle of separability, a smart attendance system in an automobile factory would not be evidence that the factory is smart because the factory's primary functions are related to producing automobiles, not taking attendance.

"Apply automated capabilities and other physical, informational, technical, and intellectual resources." The different types of resources must be mentioned if the smart things of interest are to include more than just isolated devices. For example, the smart things might be sociotechnical systems or combinations of sociotechnical and totally automated systems such as smart farms or smart cities.

"Automated capabilities for processing information." The primary components of purely social systems and noncomputerized work systems do not perform automated information processing and therefore cannot be smart in this sense. Processing information can be subdivided into capturing, storing, retrieving, transmitting, manipulating, and/or displaying information, each of which will be treated as a dimension of smartness within the category of processing information.

"Automated capabilities for interpreting information." This includes drawing conclusions from information, such as recognizing the semantics of the information and evaluating the extent to which the information is correct.

"Learning from information that may or may not be specified by its designers." This includes executing predefined scripts and capturing or creating new knowledge and internalizing that knowledge into the nominally smart entity itself.

Such careful attention to the definition of smartness might seem excessive, but actually is important for serious discussion of smart systems and devices. Aside from the general benefits of defining terms, serious attention to the definition of smartness helps in separating the discourse of smart systems and devices from common uses the term smart related to whether or not people are smart and whether or not a device or system's design has convenient or otherwise beneficial features. Systems and devices that are called smart are products of human intellect and may express aspects of the specific knowledge of individuals or groups, but should not be viewed as somehow equivalent to the intellect of any individual or group. Smartness also is not treated as a synonym of high quality, good fit to needs, or otherwise impressive or beneficial capabilities. Mixing those different views of smartness leads to confusion. A product/service that exhibits excellent quality and fits customer requirements in an extremely clever way might not exhibit smartness as defined here. Conversely, a product/service might have low quality or inadequate fit to user needs even though it exhibits some of the characteristics of smartness as defined here.

4 Classification Matrix for Smart Capabilities

Defining smartness is a step forward, but the definition provides little guidance for supporting description, analysis, and design of smart devices and systems. The next step is a classification matrix shown below Table 1, which includes a very brief description of each capability. The columns are categories of smartness, i.e., smartness related to information processing, internal regulation, action in the world beyond the device or system, and knowledge acquisition. The second, third, and fourth categories rely on capabilities in the first category, but are different enough to identify separately. It is possible for a device or system to be very smart in one or several of these categories, but not smart at all in others. For example, an ability to capture information through sensors does not imply that a device or system can use that information for internal regulation, for action in the world beyond itself, or for accumulating knowledge.

The rows in Table 1 go from scripted execution of prespecified instructions through formulaic adaptation, creative adaptation, and finally, unscripted or partially scripted invention. Effective sociotechnical systems generally have capabilities in every cell of the matrix, and usually have possibilities for improvement in some of those areas. Things that are called smart devices often have capabilities in only one or several of those areas. Scripted execution, i.e., following programmed instructions, is fundamental to all computing and generally describes sociotechnical systems whose processes are highly structured and mechanical. Formulaic adaptation is common, as in the handling of repetitive exceptions within organizational routines. Creative adaptation is more challenging due to novelty and difficulty of changing established practices. It becomes especially challenging when it involves abstraction, inference, optimization, or search to develop a new adaptation that was not specified in advance. Unscripted or partially scripted invention involves producing new understandings, methods, or artifacts using inferences or extrapolations from past, current, or projected future situations. Many sociotechnical systems perform localized invention through

Table 1 Classification matrix for smart capabilities

	Information processing	Internal regulation	Action in the world	Knowledge acquisition
Not smart at all	Does not process information	Does not perform internal regulation	Does not perform action in the world	Does not perform knowledge acquisition
Scripted execution	Execution of prespecified instructions in a computer program	Internal regulation based on a prespecified script or method	Visible action based on a prespecified script or method	Acquisition and internalization of information based on a prespecified script or method
Formulaic adaptation	Adaptation of information processing based on prespecified inputs or conditions	Adaptation of internal regulation based on prespecified inputs or conditions	Adaptation of current action in the world based on prespecified inputs or conditions	Adaptation of knowledge acquisition based on prespecified inputs or conditions
Creative adaptation	Adaptation of information processing instructions based on unscripted or partially scripted analysis of relevant information or conditions	Adaptation of a script for internal regulation based on unscripted or partially scripted analysis of relevant information or conditions	Adaptation of a script for action in the world based on unscripted or partially scripted analysis of relevant information or conditions	Adaptation of a script for knowledge acquisition based on unscripted or partially scripted analysis of relevant information or conditions
Unscripted or partially scripted invention	Unscripted or partially scripted design and execution of a workaround or new method for processing information	Unscripted or partially scripted design and execution of a workaround or new method for internal regulation	Unscripted or partially scripted design and execution of a workaround or new method related to action in the world	Unscripted or partially scripted planning and execution of a workaround or new method related to knowledge acquisition

workarounds or other unscripted or partially scripted responses to conditions that make it difficult to fulfill organizational or personal goals (e.g., see theory of workarounds – Alter (2014)). Totally automated invention is far beyond current capabilities of most totally automated systems except in rare niche areas such as drug discovery.

4.1 Dimensions of Smartness

By the definition above, the smartness of a device, totally automated system, or sociotechnical system is described as a set of dimensions that are continuous variables going from not at all smart to somewhat smart to extremely smart. Figure 1 shows the four categories of smartness from Table 1 along with a set of dimensions related to each category. For example, *self-monitoring* is one of the dimensions under the category *internal regulation*. As a reminder of the general range of possibilities for each dimension, the bottom of Fig. 1 shows *not smart at all* plus the four levels of smartness in column 1 of Table 1. Tables 2, 3, 4, and 5 expand on Fig. 1 by providing highly summarized descriptions of the "somewhat" and "extreme" parts of the dimensions for each of the categories.

The next section will illustrate that the dimensions in those tables might be used as an aid for thinking about different ways to make a device or system smarter or less smart, either of which might be more advantageous for specific purposes and/or specific stakeholders.

The dimensions in Table 2 are the six aspects of automated information processing (Alter 2006) i.e., capturing, transmitting, storing, retrieving, manipulating, and displaying information. Most of the smart things listed in this paper's introduction (e.g., smart glasses, smart locks, smart meters, and smart cities) capture information and then use that information to perform their primary functions. Some of them transmit, store, or retrieve information; some do not. Most of them manipulate information, e.g. performing calculations using the information or changing the format of the information. Many entities are somewhat smart along one or more of the six dimensions. Few are extremely smart along any of those dimensions.

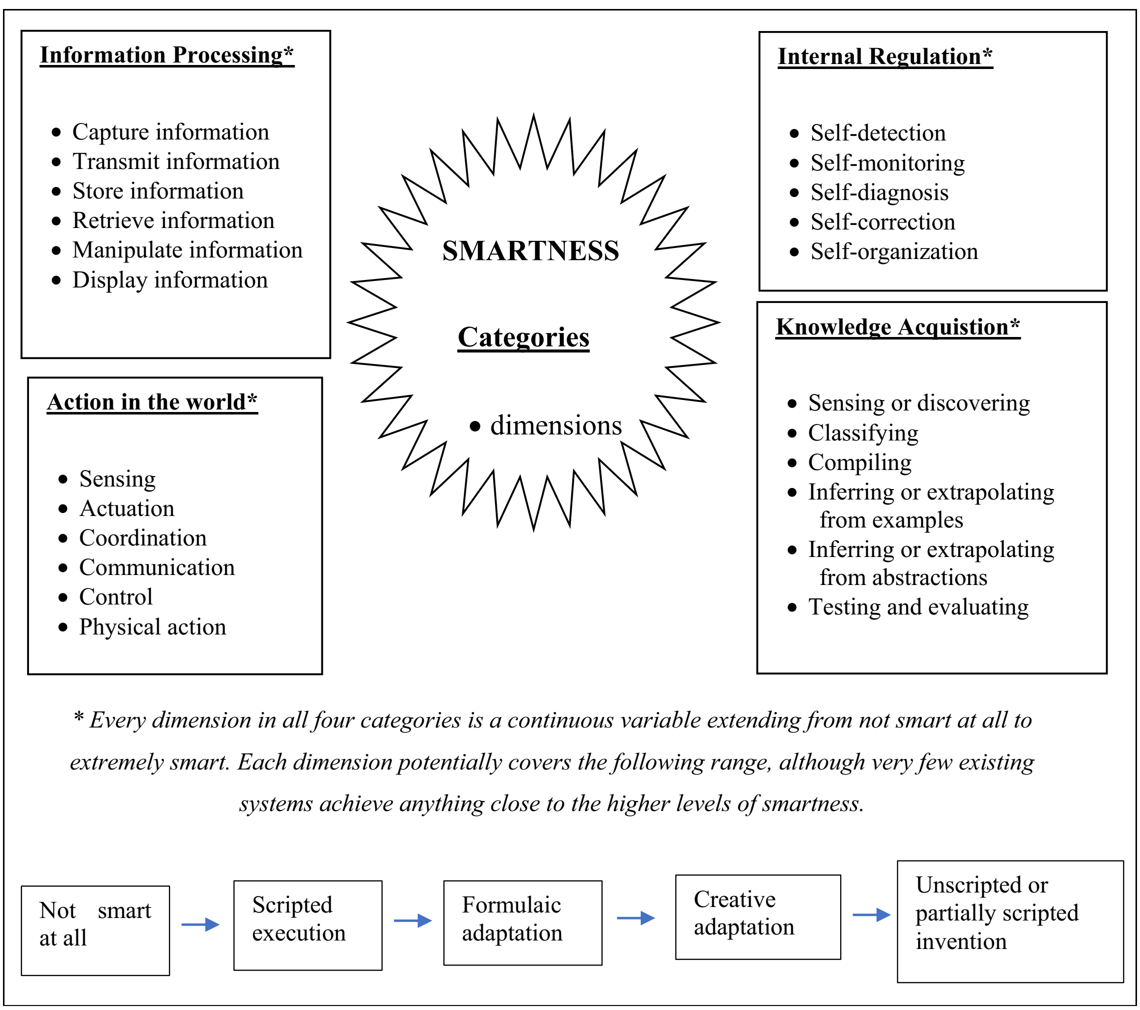

Fig. 1 Dimensions of smartness for systems, services, and devices

Table 2 Dimensions related to automated information processing in general

Dimension	Somewhat smart	Extremely smart
Capture information	Captures predefined data items using data capture techniques designed for the data captured	Uses context-related knowledge (not prespecified knowledge) to decide which information to capture and how to capture it
Transmit information	Transmits predefined data items using transmission techniques designed for the data transmitted	Uses context-related knowledge (not prespecified knowledge) to decide where information needs to be transmitted and how to transmit it
Store information	Stores predefined data using data storage techniques designed for the data stored	Uses context-related knowledge (not prespecified knowledge) to decide how and where to store information
Retrieve information	Retrieves predefined data items using data retrieval techniques designed for the data retrieved	Uses context-related knowledge (not prespecified knowledge) to decide how to find information and how to retrieve it
Manipulate information	Manipulates predefined data items or aggregations of data items using data manipulation techniques designed for the prespecified data.	Uses context-related knowledge (not prespecified knowledge) to decide what manipulation of information is needed and how to produce that result
Display information	Displays predefined data items or aggregations of data items using data display techniques designed for the prespecified data	Uses context-related knowledge (not prespecified knowledge) to decide what information would be most valuable to display

Notice Table 2's use of the terms information, data, and knowledge. The first column uses the term information because electronic signals that are processed must be information, i.e., must have some impact in relation to the function at hand. Without such impact, the data collected and transmitted, would be considered data, not information. The second column (somewhat smart) uses the term data because the physical processing occurs through applying predefined techniques to predefined data items. The fourth column (extremely smart) uses the term knowledge because extremely smart implies a higher order of purpose and semantic mastery than is implied by merely processing data.

Table 3 presents dimensions related to internal regulation, which is increasingly important as devices and systems become more automated and more autonomous. Each dimension relies on information processing and each overlaps to some extent with some of the dimensions in other categories. The five dimensions are based largely on the description of smart service system in Medina-Borja (2015).

The dimensions in Table 4 are related to various aspects of performing action in the world beyond the boundary of the nominally smart device or system. The dimensions in Table 4 involve applying information processing (see Table 2) to systemic purposes including sensing, actuation, coordination, communication, control, and physical action, topics from the description of smart service system mentioned earlier. The reference to non-scripted methods in the extremely smart column sets the bar very high because it calls for invention using techniques and goals that are determined dynamically based on the context at hand. Determining techniques and goals on-the-fly is often challenging for people. Imbuing that level of "smartness" into totally automated systems is far beyond current capabilities except possibly in certain niche situations.

Table 5 presents six dimensions related to knowledge acquisition. This dimension starts with sensing or discovering predefined data items. From there it moves to classifying and compiling data in a way that constitutes factual knowledge. More advanced dimensions involve inferring or extrapolating

Table 3 Dimensions related to internal regulation

Dimension	Somewhat smart	Extremely smart
Self- detection	Uses prespecified data and criteria to characterize its existence as separate from but possibly related to the existence of other relevant entities	Performs non-scripted activities that establish and maintain its separate identity within the surrounding ecosystem.
Self-monitoring	Uses predefined sensing techniques, criteria, and data to monitor its internal state	Uses non-scripted methods for self-monitoring in order to maintain the entity itself
Self-diagnosis	Diagnoses internal problems by applying predefined techniques and criteria to predefined data	Diagnoses internal problems by performing novel analysis not scripted in advance by designers
Self -correction	Uses predefined techniques, criteria, and data to modify internal parameters or business rules	Uses non-scripted methods for identifying deviations from past, current, or future goals and determining how to adjust or to meet those goals in the future
Self-organization	Uses predefined techniques, criteria, and data to organize its own operational structure	Uses non-scripted methods to organize different components of the entity in order to achieve its goals

Table 4 Dimensions related to action in the world

Dimension	Somewhat smart	Extremely smart
Sensing	Captures predefined data items using sensing techniques designed for the types of data that are sensed	Uses non-scripted methods to decide how to sense situations or other higher order information (e.g., work being done in a way that is not competent)
Actuation	Uses predefined methods and information to actuate activity involved in primary functions	Uses non-scripted methods for deciding what to actuate and how to perform the actuation.
Coordination	Uses predefined business rules or decision tables to support coordination of actors and/or uses of resources	Uses non-scripted methods for deciding what needs to be coordinated and how to perform the coordination
Communication	Uses predefined methods and rules for communicating with people or supporting human communication	Uses non-scripted methods for identifying communication recipients and deciding what needs to be communicated and how to perform the communication effectively
Control	Manipulates predefined data items or aggregations of data items using data manipulation techniques designed for the prespecified data.	Uses non-scripted methods for deciding what needs to be controlled and how to perform the control activities effectively
Physical action	Applies predefined business rules to gather information in the course of physical action to assure that the action is performed efficiently, effectively, and safely.	Uses non-scripted methods for planning, executing, and monitoring physical action in ways that identify and respond to exceptions and other unexpected situations.

from examples, from statistical summaries, or from abstractions, and at some point testing and evaluating the knowledge acquired.

5 Using the Dimensions of Smartness for Describing, Analyzing, or Designing Devices or Systems

A test of whether the dimensions of smartness are useful is to apply them for describing, analyzing, or designing smartness into devices or systems. Lacking an empirical test at the time of this writing, the applicability of the dimensions is illustrated by using three hypothetical examples, an imagined smart water bottle (a smart device), an imagined attempt to make a hiring service system smarter, and an imagined attempt to make a city smarter.

5.1 Use Related to a Potentially Smart Device, a Water Bottle

Imagine that a company's R&D department uses Tables 2, 3, 4, and 5 to brainstorm about different forms of smartness that might apply to product X, a smart version of the type of water bottle that some people carry around and use when exercising.

Smartness Dimensions Related to Information Processing With the necessary sensors and circuitry, X could *capture* information related to the amount of water in the bottle, the amount drunk each time the bottle is used, the temperature of the water, and even characteristics of the user such as identity, temperature, or pulse rate. The data could be *stored* and *retrieved*. It could be *transmitted* wirelessly to a phone or other device could be *manipulated* and *displayed* in graphs by using a related app.

Table 5 Dimensions related to knowledge acquisition

Dimension	Somewhat smart	Extremely smart
Sensing or discovering	Uses predefined scripts to capture predefined data items	Uses context-related knowledge (not prespecified knowledge) to decide which information to capture and how to capture it
Classifying	Uses predefined scripts to classify information	Uses context-related knowledge to decide how to classify information
Compiling	Uses predefined scripts to compile information	Uses context-related knowledge to decide how to compile information to make it as useful as possible
Inferring or extrapolating from examples or statistical summaries	Uses predefined scripts to infer or extrapolate conclusions from concrete examples or statistical summaries of examples	Uses knowledge that is not specified in the form of a script to infer or extrapolate conclusions from concrete examples or statistical summaries of examples
Inferring or extrapolating from abstractions	Uses predefined scripts to infer or extrapolate conclusions from abstractions	Uses knowledge that is not specified in the form of a script to infer or extrapolate conclusions from abstractions
Testing and evaluating	Uses predefined scripts to test or evaluate hypothesized knowledge	Uses knowledge not in the form of a script to test or evaluate hypothesized knowledge

Smartness Dimensions Related to Internal Regulation With *self-monitoring*, X could track the rate at which water was consumed. It might monitor the temperature of the water and even the presence of impurities. It might *self-diagnose* problems, such as inadequate or excessive rate of usage or presence of impurities. X might *self-correct*, if it had a way of heating, cooling, or filtering the water.

Smartness Dimensions Related to Action in the World X's tracking data from its *sensing* capabilities might be used *actuate* a visual signal that *communicates* the user's need to drink water or the fact that the water supply was impure or almost depleted. It also might *communicate* with a phone or fitness tracker. X might tighten its opening to exert *control* to prevent the user from drinking too rapidly.

Smartness Dimensions Related to Knowledge Acquisition X could *sense* data and then *classify* it in relation to the types of issues revealed. It would *compile* a history of usage including time, place, quantity, and other characteristics of each instance of usage. *Inference or extrapolation* from the compiled information could generate statistical knowledge about usage patterns for individuals and populations, plus details of individual or group idiosyncrasies.

I imagined this example of a hypothetical smart water bottle as a simple illustration of how to use the smartness dimensions. To my surprise, a Google search on "smart water bottle" found examples of products that are advertised as smart water bottles. Product reviews for smart water bottles that were available as of October 2018 (e.g., Cavanaugh 2018) mentioned smart capabilities such as tracking water intake (*capturing information*), displaying water temperature (*displaying information*), notifying the user when it is time to drink water (*communication*), and adding flavor to the water (*physical action*).

5.2 Use Related to a Sociotechnical System, a Hiring System

Imagine that managers of a technology company wanted to explore whether their hiring system might benefit from greater smartness. They know that their employees are intelligent and industrious and believe that their processes make sense. Nonetheless, they wonder whether a smarter hiring system would reduce costs and improve hiring results. The current hiring system is summarized in Table 6 using the format of a work system snapshot, a type of informal textual model that has been used by many hundreds of MBA and Executive MBA students (Alter 2013).

Smartness Dimensions Related to Information Processing Their current system contains technology that seems to process information adequately. It *captures* necessary information, *stores* it in a database where it is *retrieved* easily, provides a straightforward way of *manipulating* information to generate management reports, and *displays* the information in convenient forms. Table 2's descriptions of extremely smart information processing seem like science fiction to the managers.

Smartness Dimensions Related to Internal Regulation Looking at internal regulation highlights important problems in the system, which cannot be viewed as *self-monitoring, self-diagnosing,* or *self-correcting*. In some ways it seems

Table 6 Work system snapshot a current hiring system that might be made smarter

Customers	Product/Services
• Hiring manager • Larger organization (which will have the applicant as a colleague • HR manager (who will analyze the nature of applications)	• Applications (which may be used for subsequent analysis) • Job offers • Rejection letters • Hiring of the applicant

Major Processes and Activities	
• Hiring manager submits request for new hire within existing budget • Staffing coordinator defines the parameters of the new position. • Staffing coordinator publicizes the position. • Applicants submit job applications. • Staffing coordinator selects shortlisted applicants. • Hiring manager identifies applicants to interview.	• Staffing coordinator sets up interviews. • Hiring manager and other interviewers perform interviews. • Hiring manager and other interviewers provide feedback from the interviews. • Hiring manager makes hiring decisions. • Staffing assistant sends offer letters or rejections. • Successful applicant accepts or rejects job offer or negotiates further.

Participants	Information		Technologies
• Hiring managers • Staffing coordinator • Applicants • Staffing assistant • Other employees who perform interviews	• Job requisition • Job description • Advertisements • Job applications • Cover letters • Applicant resumes	• Short list of applicants • Information and impressions from the interviews • Job offers • Rejection letters	• HR portal for communication with applicants • HR database of applicants, applications • Word processor • Telephones • Email and messaging

self-organizing, but the CEO views that as a synonym of being excessively improvisational. The CEO believes the system needs smarter management rather than smarter technology.

Smartness Dimensions Related to Action in the World They see room for improvement in *sensing* the ability of applicants to work with others. Perhaps video or some other technology might help in detecting antisocial tendencies in applicants. Smarter *actuation* might produce a path for interviewing the most qualified applicants sooner. Smarter *coordination* might call for better scheduling of interviews. The *communication* dimension might lead to wondering whether more interviews could be done by video and whether interviewers could submit their comments by video. Smarter control of the process might involve better notifications of due dates and better feedback related to interview reports. Smarter physical action seems relevant mainly in eliminating unnecessary trips from local work sites to conference rooms at headquarters where some hiring decisions are discussed.

Smartness Dimensions Related to Knowledge Acquisition Management believes that knowledge acquisition is not a significant problem. The *sensing, classification*, and *compilation* of knowledge about hiring seems adequate. They question whether knowledge from smarter *inferences* or *extrapolations* related to *examples* or *abstractions* would make any difference. They like the idea of *testing* or *evaluating* the company knowledge about specific interviewees, but they do not know how that might be done in a smarter way.

5.3 A Societal Example: A Potentially Smart City

Assume that the city counsellors of city X sets up a smart city taskforce whose mandate is to propose capabilities that would make city X much smarter than it is now. The task force decides to look at the four dimensions of smartness to support its efforts at brainstorming. Unfortunately, several members of the task force are skeptical of the whole idea of smarter cities and emphasize their distrust of the notion of smartness by continually focusing on intrusive or error-prone aspects of smartness that they find risky or unacceptable. Here are some of their examples:

Smartness Related to Information Processing City X has extensive information processing capabilities in its data center, but might be able to capture a great deal more information. For example, it could use cameras, facial recognition, signals received by cell phone towers, RFID sensors, and other means to capture and record information about the location and movement of people and vehicles throughout the city. Later that information could be retrieved and manipulated to create a time/location history of most people and vehicles. That information could be manipulated to help in anticipating citizen and vehicle movement in real time. It could be displayed to police officers or others whose jobs sometimes call for finding or identifying people or vehicles.

Smartness Dimensions Related to Internal Regulation City X is usually viewed as well-governed, but the dimensions of internal regulation highlight possible directions for improvement. For example, the availability of real-time information about citizens and vehicles could help city X regulate many aspects of civic life. Traffic status and history information could be used for traffic control. Real-time vehicle tracking would make it possible to apply dynamic charging algorithms for driving on city streets and for parking, with charges per minute depending on the time of day, state of traffic, causing obstruction that slows other vehicles, and other factors. Ready access to citizen information also might help police find individuals or specific vehicles based on their most recent recorded positions and based on past movements. Related information could be used by school registrars, the election commission, and other city authorities to support enforcement of regulations.

Smartness Related to Action in the World The new smart capabilities in City X might allow it to perform many functions differently. For example, knowing the precise location of every vehicle at all times would allow it to generate traffic fines automatically for a vehicle that moved between two locations in a way that must have involved exceeding speed limits. With highly detailed tracking of vehicles, City X could make its parking meter system automatic, with all cars charged by the minute based on where they are parking, and what time of day, and for how long. Some of the city's bureaucratic customer service activities might be transferred to an application of Google Duplex, announced on May 10, 2018 as "a new technology for conducting natural conversations to carry out "real world" tasks over the phone. The technology is directed towards completing specific tasks, such as scheduling certain types of appointments. For such tasks, the system makes the conversational experience as natural as possible, allowing people to speak normally, like they would to another person, without having to adapt to a machine." (Leviathan and Matias 2018). That capability might make it possible to respond to many common inquiries by citizens while employing fewer expensive city workers. It might even be possible to hide the computerized nature of the agent.

Smartness Related to Knowledge Acquisition Smarter knowledge acquisition might help city X serve its citizens more effectively. Knowledge acquisition starts with compiling information. The next step is converting information into knowledge about its citizens and about the city's operation and operational problems might help in some ways. For example, city X might benefit from knowing which individual citizens and groups of citizens are most likely to commit crimes in the future. The relevant knowledge in this instance might start with some kind of propensity to illegality, which might be determined by comparing the demographic profile of every citizen with the demographic profiles of people who had been arrested and people who had been convicted of crimes. While that knowledge might help law enforcement some ways, it also would have the almost inevitable effect of leading to unwarranted searches and unjust intrusions on the lives of citizens who never committed a crime and who have no intention of committing crimes.

The city X discussion of various aspects of smartness probably would become highly contentious, with some task force members more attuned to detailed tracking and control and others more attuned to individual choice and freedom. Additional increments of smartness might seem positive to some task force members and quite negative to others. Thus, higher degrees of smartness as defined through each dimension in Tables 2, 3, 4, and 5 might be beneficial for some stakeholders and detrimental for others.

6 Conclusion

This paper presented principles that informed its view of smartness. It defined smart, presented four categories of smartness that were subdivided into 23 dimensions. It used three brief examples to show how those categories and dimensions might be used in thinking about how to make a device or system smarter. All of that was motivated by a belief that serious discussions of smartness in the context of devices, services, and systems requires clarity about the topic, i.e., a definition of smart and related categories and dimensions such as those presented here.

Relation to the Many Examples in the Introduction The three examples in the previous section illustrate how the four categories and 23 dimensions can be applied. The same general approach can be applied to every type of nominally smart thing that is mentioned in the introduction. Those things cannot be assessed in general, however. The purpose of the dimensions is to provide an organized approach for deliberating about the benefits and problems related to increasing or decreasing the degree of smartness in any specific instance of a nominally smart thing, e.g., a specific smart card, smart fabric, smart burglar alarm, or smart town. Thus, the question of whether a smart card or smart burglar alarm system is indeed smart is viewed as neither interesting nor valuable. The interesting and valuable questions are about identifying ways in which the degree of smartness in a device or system might be changed (increased or decreased) and evaluating whether those changes likely would be beneficial.

Uses of the Categories and Dimensions in Research The introduction provided an indication of the everyday nature of the claims that many types of things are smart. Research related to smart things should have a way to describe the extent to which those things are smart. Thus, research about smart cards or smart buildings or smart mirrors could use the categories and dimensions to characterize the specific examples that are being studied. Perhaps some of them barely qualify as smart, while others have surprisingly powerful capabilities. Those differences should be observed and described before producing generalizations or conclusions about whether the instances studied in a research project are representative of smartness for a specific type of device or system.

Encouraging Other Approaches to Smartness Two of the references in the Appendix (Kaisler et al. 2018) and Püschel et al. (2016)) proposed rigorous approaches to describing smartness in specific types of situations. Those approaches made sense for their purposes, even if they did not cover the same territory that this paper attempted to cover (devices, totally automated systems, and sociotechnical systems). With smart and smartness appearing so often in discussions of today's business and technical world, development of other approaches to this subject matter could have many benefits related to clarifying and improving the ideas presented here. Developing other approaches could support real world analysis and design of product/services and systems, and could help in performing rigorous research about new types of devices, platforms, systems, and methods.

When and how is it Wise to Use Smart Technologies? A separate paper could explore important topics related to the social benefits, costs, and implications of using smart technologies. Along with many other examples, the example related to smart cities shows that the use of smart technologies may or may not be beneficial to direct users of those technologies and to people impacted by them. Obvious stakeholder concerns range from privacy and surveillance through employment, equity, and wealth.

The same types of issues apply at the device level. Consider just several types of impacts of just one type of nominally "smart" device, the smart phone: Reports in the *Spine Journal* (Cuéllar and Lanman 2017) and in other sources have described "text neck" as a medical issue related to the stress on neck and postural muscles due to flexing the neck for extended time spans to look downward at smart phones. Texting on smart phones is associated with a substantial percentage of car crashes (Gliklich et al. 2016). The social scientist Sherry Turkle "found that children now compete with their parents' devices for attention, resulting in a generation afraid of the spontaneity of a phone call or face-to-face interaction." (Popescu 2018). Impacts of other smart devices and systems could be discussed as well, with the range of topics including “surveillance capitalism” (Zuboff 2015; Silverman 2016), algorithmic justice (Koene 2017), dangers of smart drones (ABC7News 2017) and the possibility that supposedly smart things make everyday life more complicated and less convenient (Chen 2018).

Future Research Defining smartness and exploring its various aspects is one of the ways to add care and specificity to discussions of how technical developments have had major consequences to date and likely will bring many positive and negative impacts in the future. Ideas in this paper could lead to future research in a number of areas. This paper identified many dimensions of smartness but did not apply those dimensions to a large set of examples. Collecting a large set of examples in real world settings (i.e., not just carefully packaged vendor or idealist descriptions of what should be) might lead to greater insight about how to describe and analyze smartness of devices and systems. Identification of both benefits and harm from real world examples could lead to more objective and less hype-laden discussions of increasingly smart devices and systems. The frontiers of smartness present an especially interesting area for future research. Tables 2, 3, 4, and 5 proposed general differences between somewhat smart versus extremely smart on 23 dimensions. Real world examples illustrating progress in the direction of extremely smart along every dimension should be of substantial interest to developers, managers, and researchers because that path is where the promise of smartness moves toward the reality of smartness.

Appendix: Searching for a Relevant Definition of Smart

As noted in the body of the text, a search of Google Scholar for various “smart” things (e.g., smart phones, smart cities, etc.) or intelligent things (e.g., intelligent machines, intelligent databases, etc.) did not come close to producing a consensus definition that is useful here. Searching the eLibrary of the Association for Information Systems, which includes leading IS journals and proceedings of major IS conferences, seemed an appropriate next step.

A search on “smart” on March 7, 2019 across the eLibrary found 4957 articles that used the term smart (759 in 2018; 671 in 2017; 448 in 2016; 426 in 2015; 342 in 2014; 365 in 2013, between 115 and 282 per year during 2007–2012; between 70 and 98 during 2000–2006; much lower numbers in earlier years). The 759 articles from 2018 demonstrated the same range of diversity as the examples in the introduction. For example, articles whose title included the term smart used that term in conjunction with the following topics: smart application development, smart cars, smart cities, smart classrooms, smart contracts, smart devices, smart glasses, smart grids, smart homes, smart locks, smart objects, smart robotic warehouses, smart service systems, smart spaces, smart speakers, smart systems, smart tourism, smart toys, and smart watches.

A more focused search looked for “smart” in the abstract of articles in the eLibrary. It found 442 articles (114 in 2018; 87 in 2017; 44 in 2016; 38 in 2015; 34 in 2014; 24 in 2013; 28 in 2012; 15 in 2011; 15 in 2010; 13 in 2009; 8 in 2008; and four or fewer in previous years).

The titles of this more manageable set of documents led to identification of papers that seemed potentially relevant for defining smartness. Many of those papers seemed valuable and interesting, but did not define smartness in a way that is useful here. For example, an article about smart technology and European standards (Jakobs 2017) said “basically, the ‘smartness’ emerges from the incorporation of ICT-enabled capabilities into ‘traditional’ applications.” Similarly, a paper presenting a taxonomy of smart elements for designing effective services for smart cities (Pourzolfaghar and Helfert 2017) said that “a smart city is an innovative city that uses … [ICT] and other means to improve citizens’ quality of life and efficiency of the urban operation and services.” The taxonomy of elements included many components, just a few of which include interoperability, usability, availability, runtime monitoring, transaction services, principles, and standards. Hirt et al. (2018) cite the following definition of from Barile and Polese 2010), “Smart service systems are “service systems that are specifically designed for the prudent management of their assets and goals while being capable of self-reconfiguration to ensure that they continue to have the capacity to satisfy all the relevant participants over time.” That type of definition expresses expectations that seem far removed from many of the examples in this paper’s introduction.

Two articles came closest to providing hints for a definition that could be used here. The first article was Kaisler et al. (2018), which defines smart object as “an object representation that is computationally aware – meaning self-defining and self-reflecting, and, possibly, self-modifying/self-adapting. … Smart objects (1) embed one or more computational models that enable the associated data to dynamically respond to CRUD (Create, Read/Retrieve, Update and Delete) operations; (2) enable higher level actions such as aggregation, negotiation, or collaboration with other smart objects; and (3) exhibit intelligent behavior.” None of the examples mentioned in the introduction satisfy this definition, although most perform some type of information processing.

The second article was Püschel et al. (2016), which presents a multi-level taxonomy of smart things “that comprises ten dimensions structured along the architectural layers of existing IoT stacks (i.e., the thing itself, interaction, data, and services).” The taxonomy subdivided those four layers into 10 dimensions: Thing (action capabilities sensing capabilities), interactions (thing compatibility, partner, multiplicity, direction), data (data usage, data source), and service (main purpose, off-line functionality). The taxonomy is much more associated with Internet of Things than with other aspects of the "smart" world, such as artificial intelligence, self-control, and knowledge acquisition.

Ultimately, ideas about smart service systems from Medina-Borja (2015), an editorial in the journal *Service Science,* which is not included in the eLibrary, provided the best hint at a possible direction for thinking about a notion of smartness that covers the Internet of Things, artificial intelligence, and the smart things mentioned in the introduction. That definition is mentioned in the body of the text.

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